# Policy Scenarios for fire-adapted communities: Understanding stakeholder risk-perceptions, using Fuzzy Cognitive Maps

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JOINT FIRE SCIENCE PROGRAM

## Abstract

Collaborative groups are most effective when the varied stakeholder groups within them understand the risks of wildfire and take proactive steps to manage these risks. Implementing policies for fire risk mitigation and adaptation, however, remains difficult because risks and policy alternatives are not understood or supported uniformly across diverse stakeholders. To facilitate greater understanding and collaboration across diverse groups, we developed a novel approach, based on Fuzzy Cognitive Maps (FCM), in which we systematically collected mental model representations from a range of stakeholders involved in wildfire management in the Ashland, Oregon area to better understand their diverse perceptions of wildfire events, wildfire impacts, and wildfire management and their willingness to support fire management policies. We used the Mental Modeler software in seven stakeholder workshops to facilitate building a group FCM. Mental Modeler helps individuals and communities capture their knowledge in a standardized format that can be used to analyze, through simulation, how the group thinks about management alternatives and what leverage points they see to improve the system under study. The data can also be used to analyze similarities and differences across stakeholder groups.

We found that city leaders and planners' mental models were focused on social and economic impacts, such as the loss of tourism income and health problems due to smoke. They emphasized the importance of the public's understanding, trust and buy-in for all planned actions. Conservationists were focused on ecosystem impacts and did not mention any social or economic impacts that restrict fire use. Fire managers at ODF and BLM were most concerned about the legal and technical constraints and the inherent risks of fire use. Small woodland owners discussed reasons for landowner inaction, including lack of enforcement of fuel reductions, absenteeism, and lack of knowledge and funds. USFS scientists and managers emphasized the complexity of decisions for fire management, due to regulatory constraints and competing management goals due to public, political, and organizational pressures, as well as technical constraints. This high complexity leads to a preference for fire suppression and prescribed burns over managed natural ignition.

Despite this diversity, there were important similarities across all groups' mental models, most notably that 1) stakeholders are aware of the ecological importance of fire and 2) stakeholder groups acknowledge the importance of the public's support and the need to better collaborate across the broader stakeholder community. A primary disagreement across groups described by this process showed that stakeholders are split in their perception of the risks associated with fire management practices: as a result of increasing prescribed fire use, the city leaders and state managers see an overall increase of fire related risk, but federal (USFS) managers expect a decrease in risk when prescribed fire is applied. When all stakeholders were combined in a final knowledge exchange workshop, participants came up with a suite of ideas aimed at overcoming barriers to fire use across management boundaries. Further, they found the mental modeling process engaging and transparent and the project results insightful and relevant for on the ground fire management.

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# 1. Background and Purpose of the Study

## 1.1 Overview

The increasing frequency, size, and cost of wildfires in the Pacific Northwest (Westerling et al. 2006) has forced communities to develop adaptation strategies that allow them to co-exist with frequent wildfires (Dombeck, Williams, and Wood 2004). Policies for fire adaptation fall into three major categories: (1) proactive approaches that accept fire as a natural occurrence but aim to reduce wildfire risk exposure (e.g., fuel reduction, building restrictions in areas on the wildland urban interface); (2) pre-fire approaches to suppress the spread of potential wildfires, such as prevention, detection, and fire safe practices (e.g., defensible space, fire safe buildings); and (3) policies for responding to an active wildfire risk, such as fire suppression and evacuation preparedness. These policies are enacted by different actors (e.g., city governments, county fire department, Bureau of Land Management (BLM) ecologists and fire managers, United States Forest Service (USFS) land and resource managers, private landowners, etc) on different geographic scales (ranging from defensible space around single homes to agency-managed forest lands), but occur in the same socio-ecological system and are therefore highly interdependent - every group's action has effects on the range of actions that other groups can take and the outcomes they can achieve. Accordingly, research and current government policy encourage the creation of cross-cutting, collaborative strategies for wildfire adaption, such as Firewise Communities and Community Wildfire Protection Plans (CWPP).

Implementing these policies, however, remains difficult because they are not understood or supported uniformly across diverse community members. Instead, stakeholders' perceptions of wildfire risks, fire impacts, and appropriate fire management practices vary, based on unique individual, environmental, and cultural experiences (Martin, Martin, and Kent 2009). The diversity in the perception of fire risks and management actions currently limits community-level fire adaptation and exacerbates the already complex issues associated with wildfire management in the Pacific Northwest.

To provide a deeper understanding of and tools for improved fire adaptation, this study examined three research questions:

1. To what degree are different stakeholder groups' mental models about wildfire risk exposure, wildfire effects, and wildfire management policies homogenous or heterogeneous?
2. Do the differences in stakeholder mental models lead to different predictions about the impacts of wildfire events and different degrees of support for wildfire management policies?
3. Does knowledge about differences and similarities in stakeholder mental models improve fire decision-makers' abilities to effectively communicate with stakeholders, reach consensus decisions, and implement fire adaptive practices?

The work builds on recent work in social science that highlights the importance of understanding and measuring mental models of different stakeholder groups when investigating human decision-making in relation to proactive adaptive behaviors and policy support.

## 1.2 Mental models

Mental models are simplified internal representations of reality that allow humans to recognize patterns and to make decisions without being overcome by the complexity of the real world. They consist of beliefs and subjective knowledge that are constructed as individuals travel through time and space and modify their understanding of the world around them (Mohammed and Dumville 2001).

Many factors impact how people think about wildfires and engage in co-management (Martin, Martin, and Kent 2009), including traditional and scientific knowledge about the local ecosystem, first-hand experience with fire (Arvai et al. 2006; Martin, Martin, and Kent 2009), cultural values and beliefs about nature (Charnley, Fischer, and Jones 2007) and individual responsibilities (Martin, Martin, and Kent 2009), objectives for land use (Tikkanen et al. 2006), the strength of home and community attachments (Kyle et al. 2010) 2010), as well as the social vulnerability of a community and its homogeneity vs. diversity (Poudyal et al. 2012). Each of these factors shapes individual mental models in unique ways, so that no two models are exactly the same. However, when people exchange knowledge, share experience, collaborate, and strive to make sense of a situation, they align parts of their mental models. This overlap allows them to reduce conflict, reach agreement, and take coordinated action within and across organizational boundaries. Accordingly, there typically is a relatively large overlap among work-related mental models within teams that successfully work together (Lim and Klein 2006). Loosely connected individuals and groups, such as the diverse stakeholders involved in Fire Adapted Community (FAC) or CWPP planning, on the other hand, can be expected to have more diverse mental models that may contain explanations, preferences, and recommendations that are in conflict with the models of other individuals and groups. This impedes their ability to take collective action.

Social scientists have recently begun to systematically capture stakeholders' mental models in order to identify similarities and differences, improve communications, and foster learning about complex problems (Biggs et al. 2011; Wood et al. 2012; Zaksek and Arvai 2004). Mental models can be elicited, documented, and mathematically modeled through a novel cognitive mapping method called Fuzzy Cognitive Mapping (FCM), used in this study.

### 1.3 Study purpose

The primary objective of this study was to improve fire adaptation at the community-level by:

1. understanding the degree of homogeneity or heterogeneity of community members' perceptions (so called 'mental models') about wildfire risks (e.g., risk management policies, exposure, and impacts);
2. assessing how these differences in understanding influence the level of support for wildfire management practices; and
3. determining local policies for fire adaptation that take these differences in stakeholder perceptions into account.

# 2. Study description and location

## 2.1 Location and Partners

Project work occurred in collaboration with the  The Nature Conservancy (TNC), which provided site access and expertise on local conditions. TNC is a key partner in the Ashland Forest Resiliency project, a collaboration between the City of Ashland, the U.S. Forest Service, the Lomakatsi Restoration Project, and the ongoing Ashland Forest All-lands Restoration Project. These efforts, which cover approx. 12,000 acres, are focused on protecting the Ashland watershed by restoring forests to their historic tree density and fuel structure. TNC is convinced that improvements already achieved can only be maintained and further improvements can only be achieved if the use of "right fire" (i.e., prescribed burns and managed natural ignition for resource benefit) is expanded. Accordingly, TNC organized (in collaboration with our research team) a series of so-called "knowledge exchanges" which aimed to increase the potential for co-managing fire in the Rogue River Basin by exploring and elucidating the barriers to right fire use, by increasing awareness of fire management options, and by developing relationships among diverse stakeholder groups. Our data collection occurred within the scope of this real-world co-management effort, which was lead by TNC. TNC identified, selected, and invited participants, based on their expertise, ability to impact co-management, support for prior initiatives, and role in the community. TNC also hosted the events.

In total, we facilitated and collected data from seven FCM-based stakeholder workshops with a total of 49 participants:

1. City of Ashland Governance and Business Leadership (City/Business Leaders, 6 participants)
2. Conservationists resistant to active management in favor of allowing all natural fire (conservationist in 2nd workshop, 3 participants)
3. Fire managers from the Oregon Department of Forestry and the Medford District Bureau of Land Management (ODF/BLM, 8 participants)
4. Local private forest and woodland owners, (Private Landowners, 7 participants)
5. River-Siskiyou National Forest fire managers (USFS, 4 participants)
6. Conservationists accepting active management (prescribed fire, fuel reduction treatments, fire suppression) + 2 participants from the 2nd workshop (conservationists in 6th workshop. 4 participants)
7. All stakeholder knowledge exchange (with participants from above workshops 1,3-5, total of 17 participants)

## 2.2  Methods

### 2.2.1 Fuzzy Cognitive Maps - Overview

Our study employed Fuzzy Cognitive Mapping (FCM) to facilitate knowledge exchanges between stakeholders, as well as to capture and analyze stakeholder mental models. FCM builds on cognitive maps - digraphs, consisting of nodes (ovals) and edges (arrows), which show the relationship between concepts of interest. Cognitive mapping has a long tradition in the social sciences (Axelrod 1976; Wood et al. 2012; Bostrom, Fischhoff, and Morgan 1992).  Comparison of map structures identifies areas of importance and agreement and disagreement between respondents (e.g., (Langfield-Smith and Wirth

1992). Recently, cognitive mapping has also been used to understand how wildfire risk and fire management practices are perceived (Zaksek and Arvai 2004) and highlight similarities and differences in the risk perceptions of experts and laypeople. A particular type of cognitive maps, so-called causal maps or cause maps, can also be analyzed with regard to structural metrics: the number of in- and outbound arrows determines if a concept is a so-called driver (i.e., impacts the model strongly), receiver (i.e., is only impacted by other concepts), or an ordinary concept (in- and outbound arrows). Moreover, the density of a map and the centrality of concepts can be determined so that map structures can be compared across multiple cognitive maps.

Fuzzy Cognitive Maps (FCM) (Kosko 1988; Kosko 1993) add a dynamic component to this analysis. They regard cognitive maps as a simple form of recursive neural networks. Concepts are equivalent to neurons and activate other concepts, but in contrast to neurons, they are not either "on" (= 1) or "off"(= 0 or -1), but can take states in-between and are therefore "fuzzy." Fuzzy concepts are non-linear functions that transform the path-weighted activations directed towards them (their "causes") into a value in [0;1] or [-1;1]. FCM calculation occurs by multiplying a vector of causal activation with the square connection matrix derived from the FCM graph. Commonly used squashing functions, such as bivalent, trivalent, sigmoid, or hyperbolic tangent functions restrict the concept states to discrete final states, such as [0;1] or [-1;0;1] or to intervals [-1;1] or [0;1] and result in a fixed state vector or in a limit cycle between a number of fixed state vectors. FCM simulations, also called dynamic analysis, thus allow researchers to assess the direction and strength of impact that a particular concept has on another concept.

### 2.2.2 FCM Data collection

Workshops 1-6 had between 3 and 8 participants each and lasted, on average, 2.5 hours. The objective of the workshop was introduced by a representative of TNC and was characterized as a knowledge exchange to identify barriers to and solutions for increased use of "good" fire in the Rogue River Basin. As researchers, we explained our role as neutral facilitators of the workshops, as well as our research interests in mental model similarity/dissimilarity. The following data were collected: (1) responses to a baseline questionnaire, given to each workshop participant, resulting in data about professional affiliation and role, experience with wildfire management issues, frequency of interaction with other stakeholder groups, individual views on prescribed burning and managed natural ignition, including expected impacts and expected agreement/disagreement with other stakeholders about impacts; (2) a group-level cognitive map model, jointly created by the workshop participants; and (3) a videotape of the group discussions while creating the group-level cognitive map.

Workshop 7, which was also organized and hosted by TNC, was held for 17 stakeholders from different groups to explore opportunities for a coordinated plan to expand fire use. We kicked off the meeting by presenting summaries of the earlier workshop results. We also organized and observed breakout sessions during which stakeholders from different groups collaboratively explored the group-specific models from the first workshop. For example, a group consisting of government representatives, landowners, and BLM worked with the model generated by BLM participants to understand BLM views, challenges, and particular constraints, and to collaboratively brainstorm ideas for improving fire use. In addition to taking notes on the discussion in the breakout groups, we collected data on how participants perceived the willingness and ability of different stakeholder groups to use fire as a management tool before and after the workshop.

We discussed the practicability and efficacy of our FCM-based facilitation method with our partners at

TNC, participants of the workshops, and participants of the Conference/Workshop titled Living in fire prone forests: Managing risks to people in nature (Ashland, June 21-23), were we presented our results in two sessions.

### 2.2.3 Data analysis

The focus of the research was to capture stakeholder mental models: Accordingly, we encouraged stakeholders to use their own terminology and to talk about any topic they considered to be relevant for overcoming barriers to increased fire use. To compare mental models across stakeholders, we subsequently standardized the FCM models resulting from the workshops, and ensured that our standardization remained true to the original intent of the workshop participants. We achieved this in multiple steps:

For WS 1-5, we modified the cognitive maps to improve clarity and to translate them into functional FCM simulation models. We summarized the workshop discussions and the structural and dynamic properties of the resulting FCM model in five reports (one for each workshop). Each report was presented to a spokesperson for the workshop's stakeholder group for review and revision until all reports were deemed to provide a correct description of the stakeholder discussion. In parallel, we coded the cognitive maps resulting from the workshops "in vivo" and iteratively refined the codes until a standardized codebook that contains all unique concepts and their meanings emerged. These codes were used to standardize the concepts in the raw cognitive maps (originating from the workshops) and the refined cognitive maps (resulting from our refinement of workshop maps and discussions with the group spokespeople). We used all available data to ensure that the code book remained true to the intentions of the workshop participants, including videos and research notes of the workshop discussions, the workshop summaries, and discussions among the research team.

The results of this analysis step are:

- Data on the content of the stakeholder-specific FCM, represented as word clouds and venn diagrams (showing shared and unique concepts for each workshop group) and percentage of topic coverage compared to an earlier cognitive map (though not FCM) study done by (Zaksek and Arvai 2004)
- Data on the structure of the stakeholder-specific FCM models such as density, centrality of concepts, and system drivers.
- Data on the dynamic behavior of the stakeholder-specific FCM models in response to various input scenarios that represent barriers to or solutions for increasing the use of fire.

A second objective of the project was to facilitate co-management by providing stakeholders with insights into how other stakeholders think about the issues related to managed natural ignition and prescribed burns. To evaluate the approach with regard to improvements in co-management, we used two types of analyses: Statistical methods were used to analyze questionnaire data about the perceived willingness and ability to increase fire use before and after workshop 7. We used text coding of workshop notes to identify fire management barriers and solutions (using the code book developed in earlier research steps) to evaluate if the FCM-based process resulted in additional insights or solutions that go beyond what was mentioned in earlier workshops or in the literature. (The analysis of our discussion about our new method with TNC, workshop, and conference participants followed an informal process - we took notes and captured likes and dislikes, as well as suggestions).

The data analysis described above implements the plans outlined in our project proposal. Additionally, we explored the potential to integrate stakeholder models into a combined FCM model that crowdsources inputs from all groups. Such a model could potentially provide a holistic view on the likely outcomes of alternative approaches to fire management. To create the model, we have standardized concept names in all FCM models that were generated during workshop 1-5. (To emulate "crowdsourcing", we did not refine the models but used them, exactly as they were generated by the crowd (i.e. workshop participants). We mathematically integrated the models into a shared model, using the approach described in (Kosko 1988).

# 3. Key findings

## 3.1 Degree of homogeneity or heterogeneity of community members' perceptions

### 3.1.1 Overall Heterogeneity

The stakeholder groups created **heterogeneous models** that all represent **unique aspects** of the "bigger picture". Figure 1 shows the number of concepts mentioned by group and how many concepts were shared vs. unique to each group. Moreover, the figure highlights the major themes of unique concepts. For example, landowners mentioned a total of 29 concepts, 9 of which were unique to the group. The unique concepts focused on the themes of personal liability, landowner inaction, and limiting factors for fire use (e.g water supply on property.) They shared 20 concepts (see yellow circle for overlap with ) with other groups (The figure excludes models by fire ecologists (WS 2 + 6), which were almost exclusively focused on ecosystem impacts. They lack socio-economic factors and risks and therefore have minimal overlap with other groups.)

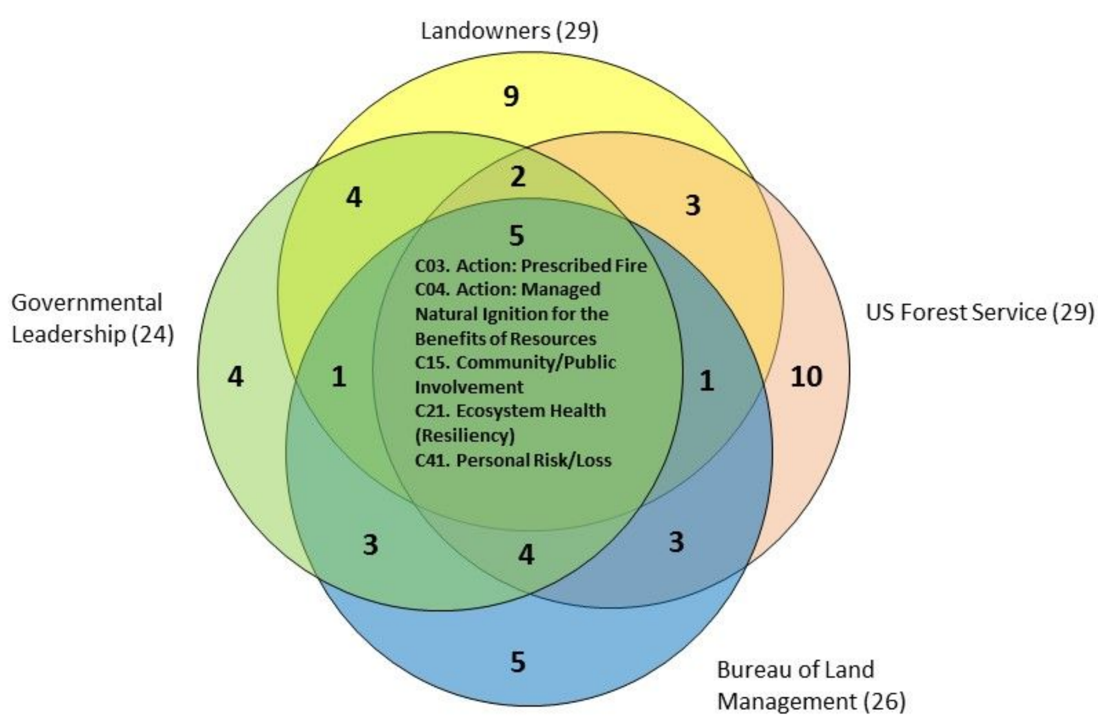



**Figure 1:** Shared and unique concepts between groups. (Note that concepts that are shared between

landowners and BLM, and between USFS and Governmental leadership are not visualized)

City/Business Leaders (WS1) were focused on social and economic impacts, such as the loss of tourism income and health problems due to smoke. They emphasized the importance of the public's understanding, trust and buy-in for all planned actions. Conservationists (WS 2 + 6) were focused on ecosystem impacts and did not mention any social or economic impacts that restrict fire use. Fire managers at ODF and BLM (WS 3) were most concerned about the legal and technical constraints and the inherent risks of fire use. They were uncertain about the extent of public acceptance of fire. Small woodland owners (WS 4) discussed reasons for landowner inaction, including lack of enforcement of fuel reductions, absenteeism, and lack of knowledge and funds. USFS (WS 5) emphasized the complexity of decisions for fire management, due to regulatory constraints and competing management goals due to public, political, and organizational pressures, and technical constraints. This high complexity leads to a preference for fire suppression and prescribed burns over managed natural ignition.

### 3.1.2 Similarity and differences between models

Despite the overall heterogeneity of models, there are also **important similarities**: all models in Figure 1 describe relationships between fire management practices and one or more of the following concepts: risk, forest health/resilience, public trust & acceptance, and smoke. These aspects were further explored with dynamic analysis/simulation, leading to the following results:

- **Stakeholders are aware of the ecological importance of fire**: accordingly, all models (but model WS 2) predict improved forest health/resilience as a result of fire use. (WS 2 predicts improved resilience for managed natural ignition but reduced resilience for prescribed burns that occur in spring). Questionnaire data shows low uncertainty with regard to this prediction.
- **Stakeholder groups acknowledge the importance of support by the public and the need collaborate with the wider community.** However, groups do not agree on how the public will react to increased fire use. The City and Business Leaders (WS 1) expect a decrease in support (triggered by smoke and its negative impacts on tourism and health), while ODF/BLM (WS 3) and USFS (WS 5) expect an increase in support for prescribed fire, as people become familiar with it. (However, USFS expects public acceptance to decrease in the case of increased managed natural ignition). Similar to risks, confidence in these predictions is low.

The dynamic analysis further shows that **stakeholders are split in their perception of the risks** associated with fire management practices: as a result of increasing prescribed fire, the City and Business Leaders (WS 1) and ODF/BLM (WS 3) see an overall increase of fire related risk, Landowners (WS 4) expect some risks to increase and others to decrease, and USFS (WS 5) expects a decrease. The WS participants expect the identical direction of change of the risk impacts in the case of managed natural ignition, with the exception of the Landowners (WS 4), who expect an overall reduction in risk. However, questionnaire data show that the participants do not have high confidence in their predictions regarding risk, indicating that they are likely to be open to adjusting their mental models.

### 3.1.3 Types of risks

Risk-related concepts were mentioned frequently (29 times in questionnaires and workshops) and entail risks to ecosystems, including watersheds and wildlife habitats, risks to the community (infrastructure and economic damages), risks to the health and wellbeing of people (firefighters, residents, recreational forest users, vulnerable populations), risks to private landowners (liability), and risk to decision-makers (career risks, liabilities) and their organizations (negative public perception, funding cuts). Overall, there appears to be a strong focus on the potential negative consequences of any action taken, as well as uncertainty about the extent of risks. In accordance with their different roles, the stakeholder groups focus on different risks. For example, private landowners were concerned about risks to their homes and about personal liability (if they take action, such as prescribed burns). BLM/ODF and USFS mentioned career risks for the decision maker and negative consequences for the entire organization as a result of a one “bad” decision.

## 3.2 Policy Preferences

### 3.2.1 Prescribed Fire and Managed Natural Ignition

All stakeholder groups expressed the desire to increase fire use in order to bring forests closer to their natural state, yet, based on their models, they have different ideas about how to achieve this goal: The City leadership (WS1) and BLM/ODF (WS2) see a fundamental trade-off between ecological objectives and social and economic factors: improvements in forest health have costs in the form of, among others, increased risks and more smoke. This effect is particularly pronounced for managed natural ignition (MNI). In contrast, USFS and private landowners do not articulate a *principle conflict* between ecological and socio-economic objectives. USFS and BLM emphasize the many regulatory and organizational constraints on increasing active fire management, indicating that the most desirable policies may not be attainable. The ecologists in WS 2 and WS 6 had little consideration for social and economic impacts and their models saw pronounced positive ecological impacts of MNI and prescribed burns that occur in late summer and fall. They have a difference of opinion regarding the impacts of prescribed burns that occur in spring: participants in WS 2 expect negative effects on forest health, while WS6 participants expect improvements.

Given the stakeholder group’s unique concerns and constraints, an increase in prescribed burns appears to have more potential for consensus than MNI, even though most stakeholders perceive MNI to be more effective than (or at least equal to) prescribed burns for achieving forest health and long-term and large-scale reductions of overall fire risk.

### 3.2.2 Policies for overcoming barriers to fire use

Questionnaires, stakeholder workshops (1-6), and the sharing of FCM models across stakeholder groups in WS 7 were all intended to identify barriers to and to brainstorm solutions to increasing active fire use. Across all these data sources, the 10 most frequently mentioned barriers are visualized in Figure 2 and the most frequently mentioned solutions are shown in Figure 3. A frequently mentioned barrier is smoke, followed by checkerboard ownership and the notion that the weather conditions in the region rarely afford the opportunity to do prescribed burns or managed natural ignitions. Other frequently mentioned barriers are risks of losses, and various concepts relating to public perception, support, and knowledge of fire management issues. The most frequently mentioned ideas for solutions target these issues indirectly, without being able to remove the root cause of the barrier: outreach and education aims to change the public's attitudes towards fire management action, risks, and smoke and the public's lack of trust. Improved coordination and leadership creates opportunities despite the checkerboard ownership. Strategic fuel reduction, better resources, and improved fire models make risks more manageable, despite local weather conditions, etc.

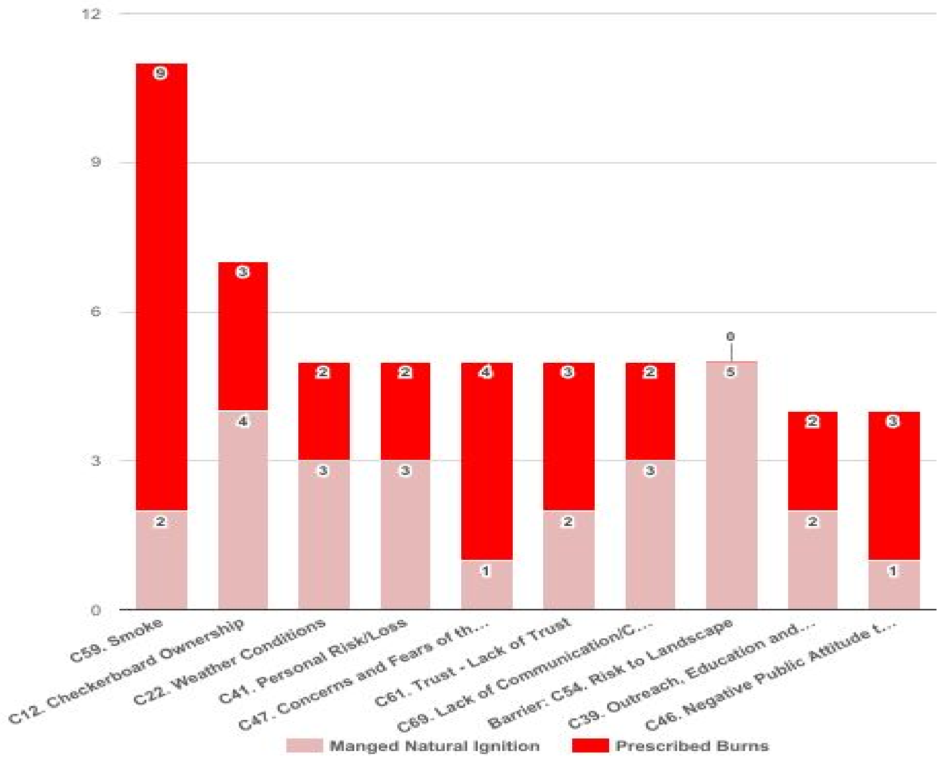



**Figure 2:** Top 10 barriers by frequency

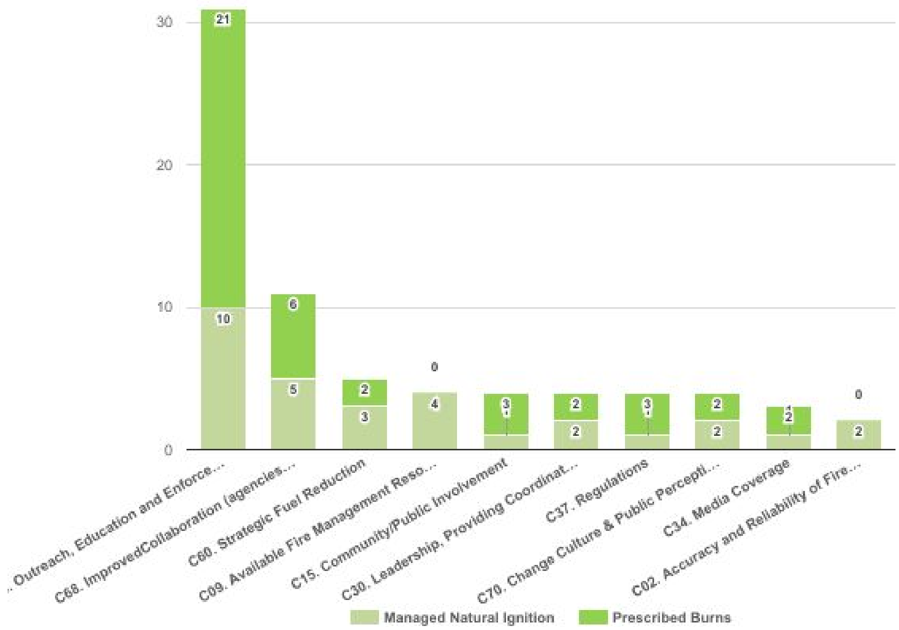



**Figure 3**: Top 10 Solutions by frequency

## 3.3 Learning about and from others

### 3.3.1 Ongoing Knowledge Exchanges

Stakeholder groups are more likely to reach a consensus when they agree on fundamentals (i.e. have mental model alignment) or, at a minimum, understand the mental models of other stakeholders. In the study, private landowners feel isolated and only report only occasional interactions that are limited to conservation groups. All other groups report on relatively broad and frequent knowledge exchanges with multiple groups. The most active role is taken by the City and Business leadership: participants in this stakeholder group have frequent interactions with all other stakeholder groups.

### 3.3.2 Facilitated Knowledge Exchanges

To investigate if and how stakeholders learn from each other in a workshop setting, we compared knowledge expressed in individual questionnaires against the knowledge that was represented in the FCM models that resulted from the workshops.

We found several cases in which a stakeholder's individual-level knowledge was not represented in the FCM model of his/her stakeholder group: For example, in the questionnaire, a participant in workshop 1 proposed to work through local health care providers to help vulnerable populations deal with the impacts of active fire management, yet this specific solution was not included in the workshop model. However, in many cases, concepts that were dropped in a particular stakeholder workshop were mentioned in other workshops, which helped them resurface 7th all-stakeholder workshop. Knowledge exchange and aggregation thus does not only occur from individual, to stakeholder group, to all-stakeholder meeting, but in a more complex pattern. The design of the 7th workshop aims to facilitate this: it introduces stakeholder-group models (from earlier workshops 1-5) and asks diverse teams to analyze them. (See evaluation of the approach in section 3.5.2).

## 3.4 Participant's recommendations for local policies

The workshops identified a variety of single issue policies, localized solutions, and overarching policy thrusts (also see Figure 3) that the stakeholders expect to result in increased fire use. We tested the outcomes of the main policies in the FCM models resulting from the workshops. Accordingly, the recommendations below only include ideas that have positive impacts on increased fire use in one or more workshop models. However, the workshop participants were not asked to determine the feasibility of these solutions, nor did they have to prioritize them. The recommendations are therefore avenue for further exploration, rather than well-defined policy options.

### 3.4.1 Overcoming structural constraints

The policy environment in the region is very complex due to, among other factors, Oregon's checkerboard ownership (intertwined patches of public and private land), the large diversity of management scales (ranging from management of defensible space around a single home all the way up to national forests managed by the USFS), a state mandate to suppress all fires during the fire season, and constraints on prescribed burns due to the Clean Air Act during times when wildfire smoke is present. Several solutions were proposed, including landowner/inter-agency agreements and land swaps (in response to checkerboard ownership), and a separate designation of naturally occurring wildfire smoke in the Clean Air Act. Some increased fire use is also possible within the existing constraints: for example, indirect suppression is permitted (*i.e.* burnout operations), which means that the overall footprint of a fire is increased within predetermined boundaries, thus effectively implementing small-scale MNI.

### 3.4.2 Communication and community engagement

Most stakeholders were very concerned and rather uncertain about the public's support for fire polices. This uncertainty makes it difficult for them to anticipate responses to any action they could take and making them reluctant to change the status quo. Stakeholders emphasize the need to effectively communicate with the public, however, without providing a lot of detail on *what* needs to be communicated. Perceived challenges to effective communication are a lack of trust in the expertise and motivations of government agencies, the difficulty of communicating respectfully and acknowledging the concerns of citizens, while also providing expert opinions, and providing timely, consistent, and relevant information to the public. Several models emphasized the need for community partnerships and trustworthy "third party" entities who can pool information about activities, programs, expert assessments, etc. from various stakeholders and communicate them to the public. A particular challenge is the messaging around risks and smoke impacts - some participants felt that some of the current communications with the public or the media cause concerns, rather than to inform. Overall, the stakeholders agree that lack of public knowledge is a major impediment to increasing fire use.

### 3.4.3 Few solutions regarding smoke and risks

While the participants identified smoke and a variety of risks as a big barrier to fire use, they offered few specific solutions on how to address these particular issues. Smoke is predominantly seen as communication problem: the public needs to be better informed about the fact that some smoke is inevitable. Only one participant in WS1 offered additional ideas, such as the hope for innovations and better technologies for smoke management (including an air curtain or dome over the Shakespeare Theater). Similarly, few solutions tackle the issue of risk reduction directly. Instead, the recommendation is to alter the public perception of risks and thus increase risk acceptance, through communication and outreach.

## 3.5 Evaluation of FCM approach in the context of fire planning

### 3.5.1 Practicality

Workshop participants found the process engaging and transparent and contributed to and corrected the FCM models that were being created. Fire managers found project results insightful and relevant. We also compared the FCM approach to other methods for capturing stakeholder risk perceptions on fire, namely an approach to create mental models from interview data and content analysis, documented in (Zaksek and Arvai 2004), which resulted in the composite mental map in Figure 2. We compared the topic coverage of this composite mental map to the topic coverage across our workshops 1-5: green concepts were identified in both studies. The overlap is very high with few exceptions: we steered participants away from discussing specific fire events (ignition sources, specific weather conditions) because we were interested in larger-scale policies. Accordingly, participants in our study failed to mention these concepts. Moreover, they failed to mention some concepts of less regional importance (e.g. historic and cultural resources, fungi & berry production) and did not detail some broader concepts, such health and safety risks. However, overall, the two studies achieved a very similar concept coverage with fewer participants (28 instead of 42) and in substantially fewer hours (12.5 hours of workshops instead of 42 hours of interviews). Moreover, our study's approach results in models that can be used for simulation, thus opening important additional avenues for analysis. Accordingly, the method developed in this grant provides an important improvement over existing approaches.

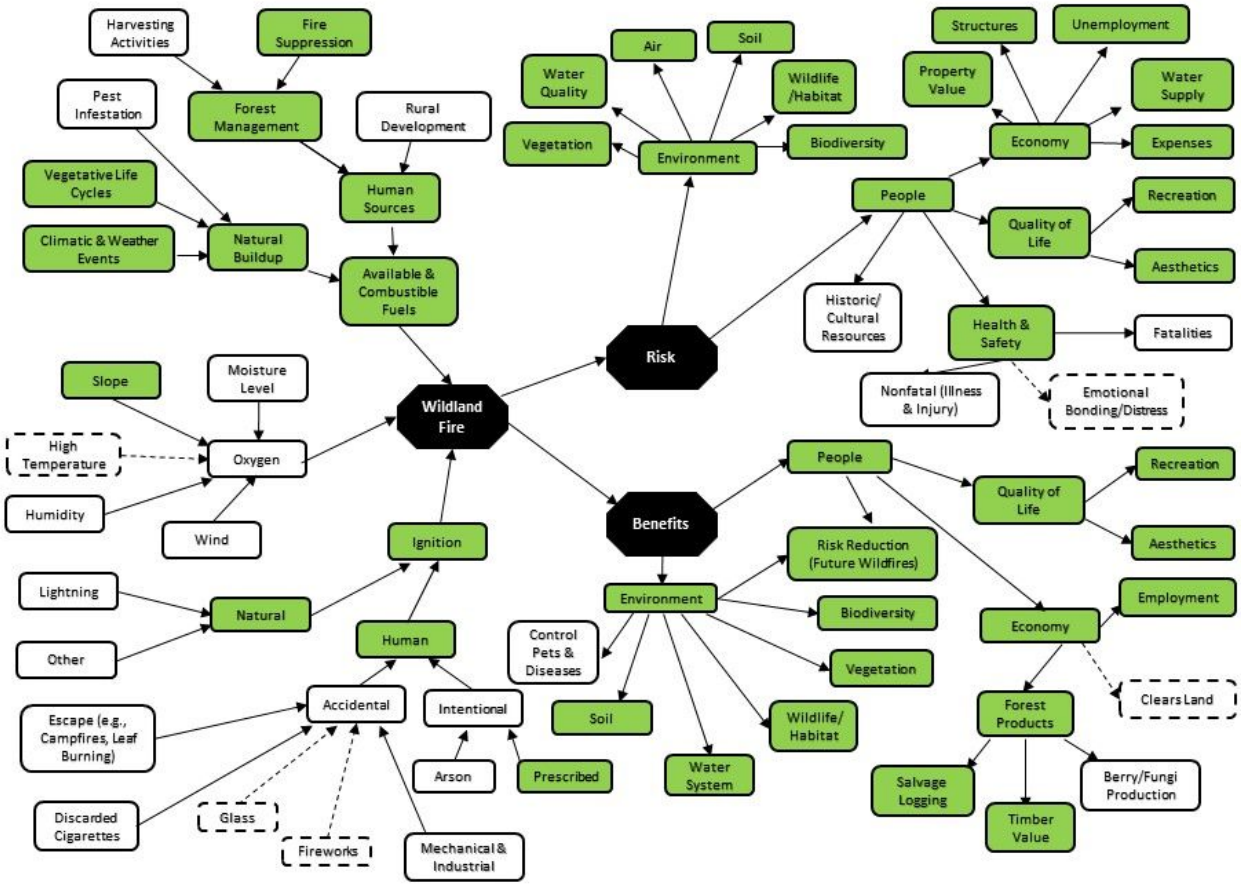
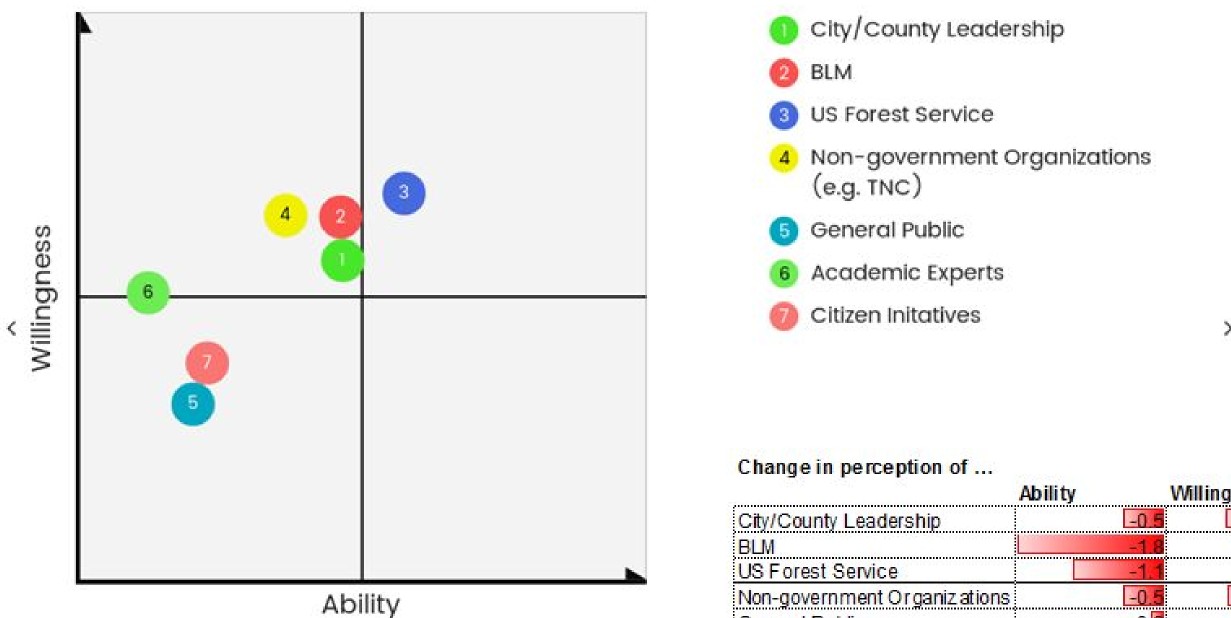



**Figure 2:** Results of FCM study (green), mapped into composite mental model from (Zaksek and Arvai 2004)

### 3.5.2 Impact on communication and consensus building

As described in section 3.3.2, the method developed in this grant aims to foster knowledge exchange between groups with different mental models. Workshop 7 asked participants to work with the FCM models from earlier workshops. This serves several important knowledge exchange functions: (1) it reintroduces/activates knowledge that may already exist within a stakeholder group but has not been fully assimilated by the stakeholder group, (2) it creates a platform for disseminating ideas across stakeholder groups and brainstorming new solutions that go beyond the ideas of any particular group , and (3) it introduces stakeholders to the mental models of other stakeholders and sensitizes them for their way of thinking.

We found evidence for all three functions: (1) The 7th workshop covered all major ideas from the individual questionnaires (including those that were not expressed in a stakeholder workshop model), demonstrating the approach's ability to pool diverse, individual-level knowledge. (2) The participants in workshop 7 came up with a variety of ideas for overcoming barriers to fire use that were new to them and other participants at the break out tables, even if similar ideas had been mentioned in earlier workshops and the literature. In many instances, the participant's solutions went beyond the already existing ideas in that they were more specific and more adapted to local conditions. Regarding the third function, we found that participants' improved knowledge of the mental models of other stakeholder groups caused them to develop a more complex understanding of challenges and potential solutions. Figure 4 shows how participants in the 7th workshop rated various organizations with regard to their ability (i.e. decision power, expertise, budget, etc.) and willingness to increase fire use. We asked the same question after they had worked with the mental models of other stakeholder groups: in all instances, we found a reduction of willingness and (to an even greater extent) ability scores. We interpret this as a more realistic view on the situation: rather than attributing limited action to other groups "not doing their job", the participants likely have a more differentiated understanding of the motivations and constraints of other stakeholders.




**Change in perception of ...**

| | Ability | Willingness |
|---|---|---|
| City/County Leadership | -0.5 | -1.1 |
| BLM | -1.8 | 0.0 |
| US Forest Service | -1.1 | -0.2 |
| Non-government Organizations | -0.5 | -1.1 |
| General Public | -0.2 | -0.9 |
| Academic Experts | -1.0 | -1.5 |
| Citizen Initatives | -0.6 | -0.5 |

(Scale 1-10)

**Figure 4:** Workshop participants' average perception of willingness and ability of various organizations to increase fire use. (Matrix shows position in a grid. Table shows change in average score from before the workshop to after the workshop)

# 4 Management Implications

The study asked stakeholders to identify concrete policies which are briefly described in section 3.4. and listed in Appendix 9.2. These proposed approaches all  provide leverage points for fire managers. In addition to the suggestions articulated by stakeholders,  the study data also uncovers management implications:

## 4.1 Use of FCM for collaborative planning

The study has demonstrated the feasibility, effectiveness and time efficiency of FCM for collaborative fire management planning. Accordingly, we recommend to use the approach developed in this work.

## 4.2 Emphasize effective risk communications

Our study found very high agreement and confidence among the stakeholders regarding the ecological benefits of fire and the risks resulting from decades of fire suppression. These findings were further corroborated by a small interview study with Ashland residents,  which we did in the scoping phase of this project. Stakeholders in this local community are not opposed to fire use per se but are concerned about the risk of  planned fires becoming unmanageable.  Accordingly, communication that is solely focused on improving ecological knowledge or shifting cultural and aesthetic values (e.g., preference for how forests look) is unlikely to increase buy-in for fire use.  In addition to outreach and education focused on the ecological impacts of fire mitigation and fire use,  conversations should incorporate communications of how risks are managed and how they are acceptable, both at a personal level (individual manager, landowner, etc) as well as at a community level. This shift will require further research (see section 6).

## 4.3 Decrease uncertainty regarding risk assessments

Stakeholders, many of which are fire experts at BLM and USFS and in city fire departments are uncertain about how exposure to risks will change as a result of increased prescribed burns and managed natural ignition. Several participants and stakeholder groups predicted that these two actions will, at least initially, *increase* overall risk exposure. This is a strong barrier to increased fire use because nobody wants to be responsible for having put people, assets, and landscapes in harm's way, or to risk one's own career for making a decision that ultimately results in losses. While more research is needed to understand the drivers of these risk perceptions, which may or may not be grounded in data  (see section 6), there clearly is a need for supporting decision makers in making "risky" active fire mitigation and management decisions.  Tools and models that standardize data- and science-driven risk assessments can help (and were proposed in several workshops), because they not only help decision makers reach decisions but also give them external validation and justification.

## 4.4 Facilitate communication channels from the general public to decision makers

Despite the very high levels of community education and outreach around fire in the Ashland region, decision makers are still uncertain about how the public feels about active fire management and expect responses to range from support to push back. Uncertainty also exists with regard to the impacts of smoke on public perception of fire (see section 6). This not only provides a barrier to decision makers who, in the face of uncertainty,  prefer an uneventful status quo over possible controversy but it likely also limits the quality of the outreach effort which may not be tailored to the community's needs. In addition to better research on community perceptions, fire managers should actively solicit input from community members, so that decision-makers know and understand community concerns and can better anticipate reactions.

### 4.5 Consider emphasizing larger scale efforts

A key concern in the complex local fire management environment is the difficulty of achieving critical mass in collaborative fire mitigation planning, which the landowners in workshop 4 described as "herd immunity". Given the overall size of the problem, many fire use and fuel treatments with limited footprints seem to be "a drop in the bucket" compared to the large scope of the problem, and seem hardly worth the temporary increase of local and individual fire risks and the potential push back by the community that some stakeholders are expecting. In order to overcome the status quo, fire managers should consider if it can be a viable strategy to move from small, local, and incremental projects towards projects with larger footprints, more visibility, more partners on higher decision levels, with shared responsibility but bigger potential gains. This would also respond to the concerns about a lack of leadership and coordination, that were identified as a barrier by several participants.

# 5 Relationship to other recent work and ongoing work on this topic

The methods developed in this project are not only suitable for  researching fire management issues, but also for investigating stakeholder groups' risk perception in different context. Moreover, the project demonstrates the need for and the potential for additional method development. Accordingly, we are currently involved in several synergistic projects.

## 5.1. Applying the method to other contexts

### 5.1.1 Understanding Risk Perception for Technology Planning

In our past work, we have used FCM modeling to synthesize public comments relating to the NEPA process for a transmission line project. However, we did not actively engage with the stakeholders, nor did we use FCM modeling workshops. This project has given us an expanded toolset that we are using to capture stakeholder concerns regarding new technologies with potentially far reaching ecological, social, and economic impacts. To this end, we are looking at public risk perceptions as they relate to the creation of public transportation concepts that integrate self-driving car technologies.

### 5.1.2 Participatory modeling to minimize ecological risks

We are currently combining collaborative FCM modeling for risk perception studies (i.e. the work in this project) with exploratory modeling approaches. This allows us to explicitly model and resolve the uncertainty surrounding risk assessments. For example, rather than asking participants to assign a strength to the causal link between "risk of escaped fire" and "risk to health and safety" we capture the range of estimates and explore model dynamics for the entire feasible range. We are currently using this approach to investigate  safety culture in oil and gas operations in order to minimize ecological risks.

## 5.2 Improving/expanding the method

### 5.2.1 Modeling narrative communications

In our workshops, we asked participants to create visual mental models. They often did so by first explaining an experience, perspective, or rationale as a narrative and subsequently translating it into an FCM model. We are currently looking into ways in which stakeholders' narratives and experiences at times of a socio-environmental crisis (e.g. the Flint water crisis, a wildfire event) can be translated into computer-based models for scenario analysis. Such tools are not readily available to modelers or decision-makers, yet narratives about acute crises often expose systemic problems that need to be understood and addressed to facilitate successful recovery.

### 5.2.2 Trade-offs in Participatory Modelling Approaches: Selecting the right tool for the job

Participatory approaches to collaborative modeling continue to become more mainstream and more software-based or web-enabled tools become available. The theoretical foundations behind each of these continues to develop with new methodological and technological advances. The theoretical foundations, and the strengths and weaknesses of different approaches should be taken into consideration when designing collaborative science projects. Accordingly, we are currently exploring the trade-offs between existing approaches: Certain participatory modeling methods may be more or less amenable to different types of marine stakeholders involved in the modeling process based on the amount of training required to create and analyze a model or to provide data points for an assessment. Although narrative scenario analysis and qualitative concept mapping lend themselves to use across a wider range of communities because they are more flexible than semi-quantitative approaches, the output of these models is often not dynamic, thus limiting their ability to be used to evaluate competing system states through post hoc analyses. Additionally, although to varying degrees most methods allow stakeholders and scientists to define the concepts, components, or variables that constitute the state space of the system modeled, some methods are more flexible in terms of the types of relationships that can be defined between variables. FCM and Agent-Based Modeling, for example, can represent feedback relationships between variables, whereas Bayesian belief network relationships are unidirectional. Although to some extent, all SESs modeled through these efforts are defined in terms of time and space, the degree to which model outputs can be interpreted in spatial or temporal units by stakeholders varies and thus may influence analytical abilities to draw meaningful conclusions that facilitate management action. When considered together on a spectrum, as tools transition from more flexible and qualitative to more parameterized and semi-quantitative, ease of stakeholder use decreases while the ability to explicitly evaluate competing system states increases. Further, although semi-quantitative approaches may provide a wide range of opportunities for post hoc analysis, they may limit the degree to which stakeholder values and knowledge are integrated into model-based assessments.

# 6 Future work needed

## 6.1 Understanding effective risk communication regarding fire

The stakeholders in this study have to weigh the risks of active fire use against the persistence of uncharacteristically dense forests, leading to a risk of for very large fires. This situation is similar to the decision of a patient who weighs the risks of a medication's side effects (which, in rare cases, may even be fatal) against the risk of leaving an illness untreated. Research in psychology, risk management, and communication has shown that such decisions are not exclusively based on probabilities but on complex cognitive processes, which cause people to find risky, but common incidents (e.g. fatal car accidents) more acceptable and less concerning than extremely rare events (e.g. terrorist attacks). Moreover, the root cause of a risk event impacts risk perceptions, regardless of its probability and effect. Our study found that members of the public (contrary to some of the experts) assess the risk of prescribed fire higher than the risks of managed natural ignition because the former is a perceived to be an interference with nature. There also appears to be a different acceptance for the health risks of wildfire smoke, depending on the source of the smoke (transient smoke from far away wildfires vs. smoke from local/regional action). Without a deep understanding of the mechanisms that shape fire risk perceptions, risk communication to decision-makers and the public is likely to fail, causing them to default to the status quo of fire suppression. Mental model research has been successfully used to understand local risk perceptions and improve the effectiveness of risk communications. However, to date, such research is largely lacking in the field of wildfire risk perceptions.

## 6.2 Understanding mental model differences that explain different fire management practices

For reasons not yet fully understood, the degree to which communities engage in prescribed burns and managed natural ignition varies widely across large geographic regions (e.g. Southeast vs. West) and even on a local scale.  Despite evolving research that identifies a growing number of cultural, social, and economic factors that impact co-management behavior (Martin, Martin, & Kent, 2009) this variance is still poorly understood. Moreover, this research provides little practical guidance: knowing that economic, educational, cultural, etc. factors in a particular community are "stacked against" co-management does little to help the community improve. We propose to shift the focus of analysis to mental model differences, which can elucidate the mechanism by which differences in community characteristics shape co-management behavior. As a first step, we propose to compare mental models in co-management vs. non-co-management communities to understand the driving forces between the different behaviors.

## 6.3 Fire decision making and innovation in government agencies

This project (and other recent studies) indicate that the general public is not fundamentally opposed to prescribed fire as long as risks are managed responsibly. Similarly, land managers, fire professionals, and elected officials see the benefits of using prescribed fire as a management tool. Nevertheless, coordinated efforts to innovate fire practices are very rare, even on lands that fall under few regulatory restriction and could serve as settings for pilot projects. Insights resulting from this project point to a possible root cause for this problem: fire managers perceive a wide gap between their own knowledge of the subject matter ("what could be done") and the knowledge of community members ("what the public thinks should be done") that causes them to hold off on initiatives because they appear too controversial or risky. Future research should investigate (1) how managers' perceptions of public opinion impacts their willingness to actively support innovative fire practices, (2) how managers' perception of public opinion impacts their assessment of the importance of existing barriers and facilitators for fire use, and (3) how managers' perception of public opinion are shaped by the information exchange and the interactions that occur in an ongoing collaborative planning process.

### 6.3 Crowdsourcing of mental models

With new advances in technology also comes new methods for understanding the dynamics of complex environmental problems drawing on the collective knowledge from distributed stakeholders through web-based technologies. For examples DESIM (Descriptive Executable Simulation Modelling), provide scientists new ways of 'crowdsourcing' mental models of groups of natural resource stakeholders asynchronously. DESIM, developed by (Pfaff, Drury, and Klein 2015) is a complementary to our FCM-based approach used in in-person workshop settings, but is an independent software package that decomposes the FCM generated in Mental Modeler into pairwise comparisons which can be converted into online survey questions and administered to large groups of users online to validate model structure and evaluate the degree to which complex understanding of resource systems are shared across local and scientific experts. Using interviews or web-based approaches to develop FCMs, DESIM asks the online participants to agree/disagree with causal connections in the model and to compare pairs of existing connections with regard to their strength. Analytical Hierarchy Process (AHP) is used to compute the strength of connections, based on all pairwise comparisons by all online study participants, thus providing a very robust, "crowdsourced" FCM model. Such approaches allow the complex structure of complex environmental systems to be defined and areas of uncertainty of the dynamics of SESs to be identified. Additionally, because FCMs are based in graph theory and matrix algebra, these platforms can be used to generate environmental and social change scenarios based on crowd knowledge to understand how these complex systems may react to future or hypothetical changes or perturbations. Tools like DESIM provide new approaches to scale-up the type of participatory planning research.

# 7 Deliverables

## 7.1 Deliverable crosswalk table

| Proposed | Explanation | Status |
|---|---|---|
| (1) A generalized method for FCM-based collection of data on mental models from a range of stakeholder groups and the FCM-based simulation of their likely responses to proposed fire management policies | The method was developed, applied and evaluated as part of this research | Completed and documented (see Deliverable 5 & 6) |
| (2) Community-level models of fire, by experts and stakeholder groups for one particular community, that can be easily adapted to similar communities in the region, | Given their diversity, we do not recommend to apply/superimpose them on other communities. Instead we recommend to use the process developed in this project (deliverable 1) do develop community-specific models | Completed: 7 community-level models completed.<br><br>5 fully usable models documented in case study report for practitioners |
| (3) a NFSC workshop which introduces and reviews the method, work completed and makes recommendations for future research | Replaced by workshop “Living in fire prone forests; managing risks to people and nature”, organized by TNC, SOFRC, FLN, Fire Adapted Communities | Delivered on June22/23 in Ashland, OR |
| (4) training of a post-doctoral scientist; | Replaced by training of graduate students (see approved budget change)<br><br>Graduate students involved in this project and status of their work:<br>Pei Zhang, preparing research proposal to transfer the method developed in this project to technology risk assessment<br>Oussama Laraichi, taking courses and completing independent study on project data<br>Alison Singer, preparing research proposal to investigate the role of narrative in system | ongoing |

| | | |
|---|---|---|
| | knowledge | |
| (5) at least two peer reviewed papers (e.g. about the method applied to fire science, and the case study application of this work) | 1. International Journal of Wildland Fire (Case Study)<br>2. Conservation Letters (Research Note on method)<br>3. Organizational Behavior and Human Decision Processes (Data on knowledge flows and knowledge pooling) | Manuscript in preparation (1, 3)<br>Under review (2) |
| (6) a standard operation procedure document for the application of this method to other fire planning and management regions across the U.S | | Completed,<br>Will be made available at mentalmodeling.org |
| (7) a webinar to be disseminated by NFSC | Understanding Stakeholder Perceptions of Fire with Mental Modelling: A case study from Ashland, OR | In progress, scheduled for March 6 |
| (8) a research brief detailing the principle findings of the research. | | In progress in collaboration with Northwest Fire Science Consortium, to be distributed following publication of journal article(s) |

## 7.2 Additional Deliverables (not in project proposal)

**Project Website and Software** : We created a project website (www.mentalmodeling.org) which we are using for outreach to practitioners. We will make deliverable 1, 6-8 available on the site and also provide links to all upcoming publications. In addition, we made substantial improvements to Mentalmodeler (open source software for FCM modeling) to reflect method innovations resulting from this project. The software is available, free of charge, at www.mentalmodeler.org.

**Case study report for fire practitioners:** Policy Scenarios for fire-adapted communities: Understanding stakeholder risk-perceptions in Ashland, Oregon (made available on www.mentalmodeling.org)

**Presentations (2):** "Living in fire prone forests: managing risk to people and nature" (Conference in Ashland, June 2016, organized by FLN, Fire Adaptive Communities Learning Network, TNC, SOFRC).

**Presentation:** at Innovations in Collaborative Modeling (Lansing, Michigan, June 2016)

**Presentation:** at Fuzzy Cognitive Map Summer School ( Volos, Greece, July 2016)

**Presentation**: at Summer Workshop on FCM (Portland, August 2016).

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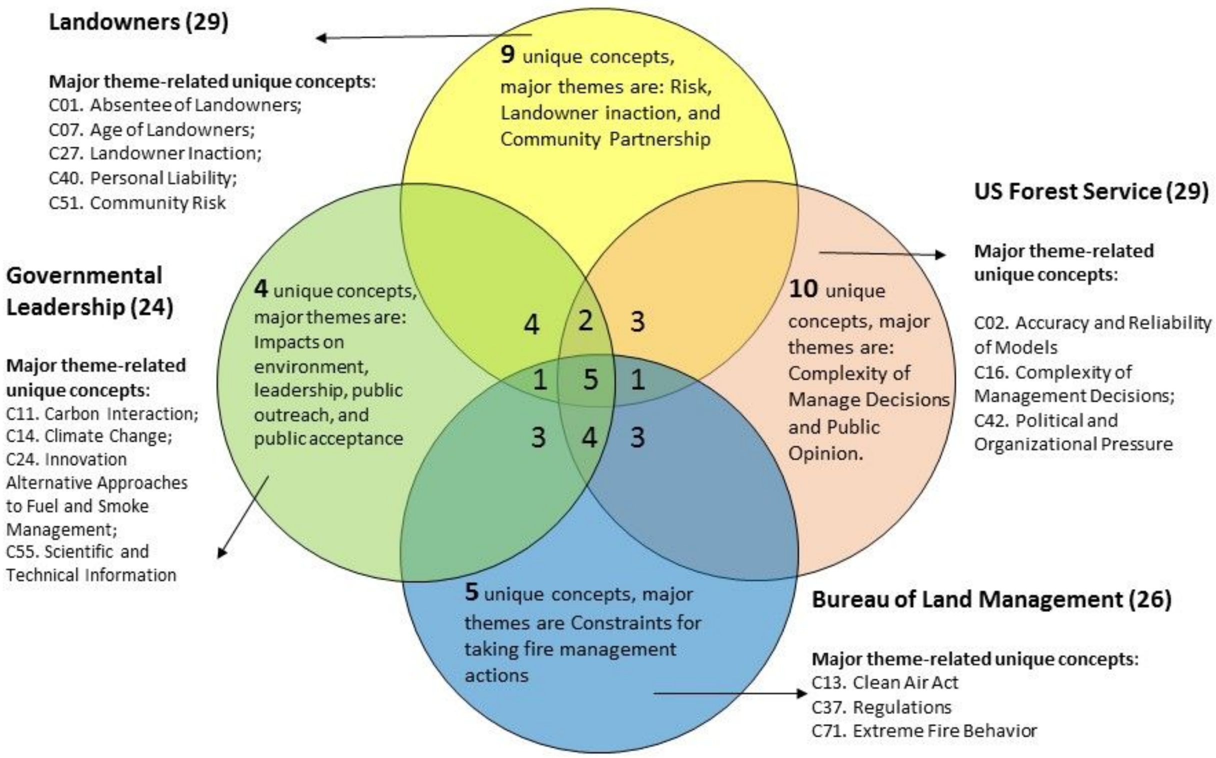
# 9. Appendices

## 9.1 Appendix 1: Detailed Venn Diagram and Full List of Concept Comparison Analysis:




(produced with Online Venn Diagram Tool: Heberle, H.; Meirelles, G. V.; da Silva, F. R.; Telles, G. P.; Minghim, R. InteractiVenn: a web-based tool for the analysis of sets through Venn diagrams. BMC Bioinformatics 16:169 (2015).)

Appendix 9.1 - continued

## List of all concepts in workshop models WS1, WS 3-5

**<u>1- Unique Concepts - mentioned by only one group (27):</u>**

**Governmental Leadership Group (4):**

C11. Carbon Interaction
C14. Climate Change
C24. Innovation Alternative Approaches to Fuel and Smoke Management
C55. Scientific and Technical Information to Lay Public

**Bureau of Land Management Group (5):**

C05. Action: Pile Burning or Slash Burning (Broadcast)
C13. Clean Air Act
C19. Desired Fire Behavior
C37. Regulations
C71. Extreme Fire Behavior

**Landowners Group (9):**

C01. Absentee of Landowners
C07. Age of Landowners
C18. Crown Ignition
C27. Landowner Inaction
C38. Other Priorities
C40. Personal Liability
C51. Community Risk
C64. Vulnerability
C66. Water Supply

**U.S. Forest Service Group (9):**

C02. Accuracy and Reliability of Models
C12. Checkerboard Ownership
C16. Complexity of Management Decision
C28. Landscape Heterogeneity
C34. Media Coverage
C36. Opportunity for Decision-making
C42. Political and Organizational Pressure
C53. Risk to Firefighters
C62. Correct Timing of Fire Actions
C63. USFS Liability

**<u>2-Groups Shared Concepts (18):</u>**

**Governmental Leadership Group w./ Bureau of Land Management Group (3):**

C20. Ecological Integrity (Manmade Effect)
C32. Impact on Aesthetics Short Term
C47. Concerns and Fears of the Public

**Governmental Leadership Group w./ Landowners Group (4):**

C30. Leadership, Providing Coordinated Management
C31. Long-term Orientation
C35. Non-defensive Fire Communication
C57. Short-term Orientation

**Governmental Leadership Group w./ U.S. Forest Service Group (1):**

C08. Agreement on Values to be Protected

**Bureau of Land Management Group w./ Landowners Group (4):**

C17. Cost of Fire Actions
C23. Fuel
C49. Recreational Value
C67. Wildlife Habitat

**Bureau of Land Management Group w./ U.S. Forest Service Group (3):**

C10. Regulations
C22. Weather Condition
C52. Risk to Decision-makers' Career

**Landowners Group w./ U.S. Forest Service Group (3):**

C26. Lack of Understanding
C43. Prior Fire History
C60. Strategic Thinning

**3-Groups Shared Concepts (8):**

**Governmental Leadership Group w./ Bureau of Land Management Group w./ Landowners Group (1):**

C48. Population Health

**Governmental Leadership Group w./ Bureau of Land Management Group w./ U.S. Forest Service Group (4):**

C45. Public Acceptance of Consequences and Impacts
C46. Public Attitude of Fire Management Actions
C50. Risk of Escape Fire
C59. Smoke

**Governmental Leadership Group w./ Landowners Group w./ U.S. Forest Service Group (2):**

C39. Outreach, Education and Enforcement
C61. Trust

**Bureau of Land Management Group w./ Landowners Group w./ U.S. Forest Service Group (1):**

C09. Available Fire Management Resources

**4 - All-Groups Shared Concepts (5):**

C03. Action: Prescribed Fire
C04. Action: Managed Natural Ignition for Resource Benefit
C15. Community/Public Involvement
C21. Ecosystem Health (Resiliency)
C41. Personal Risk/Loss

## 9.2 Appendix 2: Barriers and Solutions (proposed by participants, coded to key concepts in the FCM Models and Questionnaires, and compared to the literature)

| PB[1] or MNI[2] | Type | Idea | Concept Code | Academic fire literature that mentions the same barrier or solution |
|---|---|---|---|---|
| PB | B[3] | Smoke | C59 | Hardy, Colin C., et al. "Smoke management guide for prescribed and wildland fire: 2001 edition." (2001). |
| PB | B | Public Health | C48 | Bowman, David MJS, and Fay H. Johnston. "Wildfire smoke, fire management, and human health." EcoHealth 2.1 (2005): 76-80. |
| PB | B | Ecological Integrity | C20 | Keeley, Jon E. "Fire management impacts on invasive plants in the western United States." Conservation Biology 20.2 (2006): 375-384. |
| PB | B | Lack of available resources for FM | C09 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| PB | B | Loss of Recreational Value | C49 | Taylor, Jonathan G., and Terry C. Daniel. "Prescribed fire: Public education and perception." Journal of Forestry 82.6 (1984): 361-365. |
| PB | B | Public Acceptance | C45/C46 | Winter, Gregory J., Christine Vogt, and Jeremy S. Fried. "Fuel treatments at the wildland-urban interface: common concerns in diverse regions." Journal of Forestry 100.1 (2002): 15-21. |
| PB | B | Lack of information | C43 | Shindler, Bruce, and Eric Toman. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." Journal of Forestry 101.6 (2003): 8-15. |
| PB | B | Concerning ground fuel levels | C23 | Agee, James K., and Carl N. Skinner. "Basic principles of forest fuel reduction treatments." Forest Ecology and Management 211.1 (2005): 83-96. |
| PB | B | Lack of trust | C61 | Shindler, Bruce, and Eric Toman. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." Journal of Forestry 101.6 (2003): 8-15. |
| PB | B | Management of risk assessment | C16 | Calkin, David E., et al. "A real-time risk assessment tool supporting wildland fire decision making." Journal of Forestry 109.5 (2011): 274-280. |
| PB | B | Dry conditions/Low humidity | C22 | Cary, Geoffrey J., et al. "Relative importance of fuel management, ignition management and weather for area burned: evidence from five landscape–fire–succession models." International Journal of Wildland Fire 18.2 (2009): 147-156. |
| PB | B | Public concern of escape fire | C47 | Shindler, Bruce, and Eric Toman. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." Journal of Forestry 101.6 (2003): 8-15. |
| PB | B | DEQ regulations | C37 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| PB | B | Checkerboard with private adjacency | C12 | N/A |
| PB | B | Cost | C17 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern |

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| | | | | Journal of Applied Forestry 25.4 (2001): 149-153. |
| PB | B | Personal Risks | C41 | Winter, Greg, and Jeremy S. Fried. "Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland-urban interface." Society & Natural Resources 13.1 (2000): 33-49. |
| PB | B | Lack of efficient land management | C16 | N/A |
| PB | B | Lack of Fire Management Education | C26 | Taylor, Jonathan G., and Terry C. Daniel. "Prescribed fire: Public education and perception." Journal of Forestry 82.6 (1984): 361-365. |
| PB | B | Liability | C40 | Winter, Greg, and Jeremy S. Fried. "Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland-urban interface." Society & Natural Resources 13.1 (2000): 33-49. |
| PB | B | Complexity of fire execution | C71 | Pahl-Wostl, Claudia. "The implications of complexity for integrated resources management." Environmental Modelling & Software 22.5 (2007): 561-569. |
| PB | B | Lack of organization | C70 | Biswell, Harold Hubert. Prescribed burning in California wildlands vegetation management. Univ of California Press, 1989. |
| PB | B | Risk of control lost on community and nature | C50/C51 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| PB | B | Burns timing windows | C62 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| PB | S[4] | Education | C39 | Loomis, John B., Lucas S. Bair, and Armando González-Cabán. "Prescribed fire and public support: Knowledge gained, attitudes changed in Florida." Journal of Forestry 99.11 (2001): 18-22. |
| PB | S | Collaboration | C68 | Fernandes, Paulo M., et al. "Prescribed burning in southern Europe: developing fire management in a dynamic landscape." Frontiers in Ecology and the Environment 11.s1 (2013). |
| PB | S | Work with vulnerable people | C64 | N/A |
| PB | S | Work with local health care practitioners | C15 | N/A |
| PB | S | Enhance global fire management | C16 | N/A |
| PB | S | Acknowledgement of the barriers facing the different stakeholders | C16 | Steelman, Toddi A., and Sarah M. McCaffrey. "What is limiting more flexible fire management—public or agency pressure?." Journal of Forestry 109.8 (2011): 454-461. |
| PB | S | Acceptance of the desirability of fire | C19 | Loomis, John B., Lucas S. Bair, and Armando González-Cabán. "Prescribed fire and public support: Knowledge gained, attitudes changed in Florida." Journal of Forestry 99.11 (2001): 18-22. |
| PB | S | Mechanical remove | C08 | N/A |

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| | | of the biomass | | |
| PB | S | Public Involvement | C15 | Loomis, John B., Lucas S. Bair, and Armando González-Cabán. "Prescribed fire and public support: Knowledge gained, attitudes changed in Florida." Journal of Forestry 99.11 (2001): 18-22. |
| PB | S | Regulations' change | C37 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| PB | S | More fundings | C09 | Mutch, Robert W., et al. "Forest health in the Blue Mountains: a management strategy for fire-adapted ecosystems." (1993). |
| PB | S | Gaining stakeholders and public trust | C61 | Cortner, Hanna J., et al. "Public support for fire-management policies." Journal of Forestry 82.6 (1984): 359-361. |
| PB | S | Allowing burning on more questionable days | C30 | N/A |
| PB | S | Laws protecting landowners | C37 | Winter, Greg, and Jeremy S. Fried. "Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland-urban interface." Society & Natural Resources 13.1 (2000): 33-49. |
| PB | S | Technical assistance for landowners | C55 | Winter, Greg, and Jeremy S. Fried. "Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland-urban interface." Society & Natural Resources 13.1 (2000): 33-49. |
| PB | S | Media (press, social media) coverage | C34 | Pyne, Stephen J. Introduction to wildland fire. Fire management in the United States. John Wiley & Sons, 1984. |
| PB | S | Strategic Thinking | C60 | N/A |
| PB | S | Mitigating Fuel loads | C23 | Agee, James K., and Carl N. Skinner. "Basic principles of forest fuel reduction treatments." Forest Ecology and Management 211.1 (2005): 83-96. |
| PB | S | Adjust policies | C42 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| PB | S | Land swap to avoid checkerboard effect | C12 | N/A |
| MNI | B | Fear | C47 | Winter, Greg, and Jeremy S. Fried. "Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland-urban interface." Society & Natural Resources 13.1 (2000): 33-49. |
| MNI | B | Lack of knowledge | C26 | Shindler, Bruce, and Eric Toman. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." Journal of Forestry 101.6 (2003): 8-15. |
| MNI | B | Lack of Trust | C61 | Shindler, Bruce, and Eric Toman. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." Journal of Forestry 101.6 (2003): 8-15. |
| MNI | B | Too much jurisdictions | C70 | Steelman, Toddi A., and Sarah M. McCaffrey. "What is limiting more flexible fire management—public or agency pressure?." Journal of |

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| | | involved | | Forestry 109.8 (2011): 454-461. |
| MNI | B | Smoke | C59 | Hardy, Colin C., et al. "Smoke management guide for prescribed and wildland fire: 2001 edition." (2001). |
| MNI | B | Private property impacts | C41 | Winter, Greg, and Jeremy S. Fried. "Homeowner perspectives on fire hazard, responsibility, and management strategies at the wildland-urban interface." Society & Natural Resources 13.1 (2000): 33-49. |
| MNI | B | Loss of habitat | C67 | N/A |
| MNI | B | Risk to landscape | C54 | Steelman, Toddi A., and Sarah M. McCaffrey. "What is limiting more flexible fire management—public or agency pressure?." Journal of Forestry 109.8 (2011): 454-461. |
| MNI | B | Lack of community involvement | C15 | Shindler, Bruce, and Eric Toman. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." Journal of Forestry 101.6 (2003): 8-15. |
| MNI | B | Negative public attitudes | C47 | Shindler, Bruce, and Eric Toman. "Fuel reduction strategies in forest communities: A longitudinal analysis of public support." Journal of Forestry 101.6 (2003): 8-15. |
| MNI | B | Political pressures | C42 | Steelman, Toddi A., and Sarah M. McCaffrey. "What is limiting more flexible fire management—public or agency pressure?." Journal of Forestry 109.8 (2011): 454-461. |
| MNI | B | Complexity | C71 | Pahl-Wostl, Claudia. "The implications of complexity for integrated resources management." Environmental Modelling & Software 22.5 (2007): 561-569. |
| MNI | B | Social and Political acceptance | C45 | Steelman, Toddi A., and Sarah M. McCaffrey. "What is limiting more flexible fire management—public or agency pressure?." Journal of Forestry 109.8 (2011): 454-461. |
| MNI | B | Risk to federal land managers | C63 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| MNI | B | Fuel levels | C23 | Agee, James K., and Carl N. Skinner. "Basic principles of forest fuel reduction treatments." Forest Ecology and Management 211.1 (2005): 83-96. |
| MNI | B | Weather conditions | C22 | Pyne, Stephen J. Introduction to wildland fire. Fire management in the United States. John Wiley & Sons, 1984. |
| MNI | B | Checkerboard with private adjacency | C12 | N/A |
| MNI | B | Past fire exclusion | C43 | Parsons, David J., and Steven H. DeBenedetti. "Impact of fire suppression on a mixed-conifer forest." Forest Ecology and Management 2 (1979): 21-33. |
| MNI | B | Climate Change | C14 | Millar, Constance I., Nathan L. Stephenson, and Scott L. Stephens. "Climate change and forests of the future: managing in the face of uncertainty." Ecological applications 17.8 (2007): 2145-2151. |
| MNI | B | Land use objectives | C29 | Pyne, Stephen J. Introduction to wildland fire. Fire management in the United States. John Wiley & Sons, 1984. |
| MNI | B | Risk to community | C51 | Steelman, Toddi A., and Sarah M. McCaffrey. "What is limiting more |

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| | | | | flexible fire management—public or agency pressure?." Journal of Forestry 109.8 (2011): 454-461. |
| MNI | B | Fear of not being able to control the fire | C50 | N/A |
| MNI | B | Fire season | C62 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| MNI | B | Lack of organization | C70 | Haines, Terry K., Rodney L. Busby, and David A. Cleaves. "Prescribed burning in the South: trends, purpose, and barriers." Southern Journal of Applied Forestry 25.4 (2001): 149-153. |
| MNI | B | Lack of Resiliency | C21 | N/A |
| MNI | S | Resiliency | C21 | Chapin, F. Stuart, et al. "Planning for resilience: modeling change in human–fire interactions in the Alaskan boreal forest." Frontiers in Ecology and the Environment 1.5 (2003): 255-261. |
| MNI | S | Education | C39 | Cortner, Hanna J., et al. "Public support for fire-management policies." Journal of Forestry 82.6 (1984): 359-361. |
| MNI | S | Collaboration | C68 | Fernandes, Paulo M., et al. "Prescribed burning in southern Europe: developing fire management in a dynamic landscape." Frontiers in Ecology and the Environment 11.s1 (2013). |
| MNI | S | Enhance global fire management | C16 | N/A |
| MNI | S | Public Involvement | C15 | Cortner, Hanna J., et al. "Public support for fire-management policies." Journal of Forestry 82.6 (1984): 359-361. |
| MNI | S | Strategic Thinking | C60 | N/A |
| MNI | S | Mitigating Fuel loads | C23 | Agee, James K., and Carl N. Skinner. "Basic principles of forest fuel reduction treatments." Forest Ecology and Management 211.1 (2005): 83-96. |
| MNI | S | Adjust policies | C42 | Steelman, Toddi A., and Sarah M. McCaffrey. "What is limiting more flexible fire management—public or agency pressure?." Journal of Forestry 109.8 (2011): 454-461. |
| MNI | S | Limit summer wildfire | C62 | N/A |
| MNI | S | Change the culture of wildfire suppression | C72 | N/A |
| MNI | S | More aggressive approach by fire managers | C30 | Collins, Brandon M., et al. "Challenges and approaches in planning fuel treatments across fire-excluded forested landscapes." Journal of Forestry 108.1 (2010): 24-31. |
| MNI | S | Reduce negative perception of fire | C08 | Cortner, Hanna J., et al. "Public support for fire-management policies." Journal of Forestry 82.6 (1984): 359-361. |
| MNI | S | Prescribed burns on small lands | C58 | N/A |
| MNI | S | Leadership | C30 | Montiel, Cristina, and Daniel Thomas Kraus. Best practices of fire use: |

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| | | | | prescribed burning and suppression: fire programmes in selected case-study regions in Europe. European Forest Institute, 2010. |
| MNI | S | Build social capacity and acceptance | C19 | Loomis, John B., Lucas S. Bair, and Armando González-Cabán. "Prescribed fire and public support: Knowledge gained, attitudes changed in Florida." Journal of Forestry 99.11 (2001): 18-22. |
| MNI | S | Model with greater accuracy | C02 | N/A |
| MNI | S | Land swap to avoid checkerboard effect | C12 | N/A |